Simulation-based learning of invasive procedures skills: a critical appraisal of its organization in undergraduate medical education

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Aims: Critically appraise the organization (teachers, resources, pedagogy) of simulation-based learning of invasive procedures skills (venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation) according to the literature and create a theoretical framework for different contexts of undergraduate medical education.

Background: In different countries, requirements for graduates of medical schools include performance of invasive procedures skills. Teaching approaches to training students in simulation settings are considered in the literature. However, there is no information about the organization of such training.

Main results: A unified methodology of skills performance teaching/assessment at least at national level is not fixed; there is a tendency of 'task shifting' the training from teachers to student peers, who can play the role of simulated patients; video recording is a helpful option for educational processes; students' opinions are important for evaluating the organization of simulation-based training. A theoretical framework was developed.

Conclusion: The framework offers a generic template to complete and improve simulation-based learning in a specific context. Organizational aspects should be considered in any research on simulation-based education to better understand context and adapt delivery in other educational establishments.

Keywords: organization, management, medical, simulation, basic, skills, undergraduate.

Introduction

Background

Undergraduate medical education is a basic level of study for medical doctors across the world [1]. Regardless of future specialties, undergraduate students should achieve definite educational outcomes to qualify as a doctor. There are diverse establishments that set these requirements, usually based on country [2,3,4]. For instance, in the UK it is the General Medical Council [5].

The requirements of all establishments include evidence of skills in invasive medical procedures, which are defined as 'entering the body, usually by cutting or puncturing the skin or by inserting instruments into body' [6]. These skills are venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation, measuring blood glucose, taking nose, throat and skin swabs and skin suturing [5].

In terms of preparedness of undergraduate medical students to perform these skills, data are contradictory [7,8]. However, according to the General Medical Council [7] 14,8% (95% CI is not reported) of UK graduates were unprepared in different practical procedures in 2013. As for other countries, the average rate of inexperience during undergraduate study of such skills as urinary catheterisation, intravenous cannulation, venipuncture and nasogastric tubing was 26,75% (95% CI 18,55-35,54%) in ten developed and developing countries in 2014 [9]. To improve such skills training, consideration of ethical aspects and patients' rights are required. Not all patients would agree to have a procedure performed by a student. However, simulation-based education allows achievement of the same aims without compromising either [10].

There is a set of diverse simulation technologies and teaching methods available, including for invasive skills. For example, intravenous catheterisation can be trained with either low- or high-fidelity equipment [11]. In this example, the low-fidelity simulator is a computer system without physical responsiveness for the learner. The high-fidelity one involves complex, human-sized equipment, which allows simulation of real clinical cases.

While every medical school has its own experience in teaching invasive procedures, the integration of simulation-based training into undergraduate curriculum varies. For instance, there is a specific simulation-based curriculum at the Keck School of Medicine of the University of Southern California (USA) or a six-part course at the Medical University of Graz (Austria) [12,13]. However, this ought to be considered carefully [14].

Not only should teaching approaches be taken into account, but organizational aspects as well. These can include teachers (for instance, physicians/non-physicians), resources (salary, equipment, etc.), pedagogy (theoretical preparedness before skills training, time between training and clinical practice, etc.). This would help curriculum/policy makers and administrations of universities to streamline different types of study, including simulation, during the whole of undergraduate medical education.

Current literature data and the review focus

A preliminary literature search using PubMed database was performed and revealed a lack of data about the organization of simulation-based training of invasive skills. For example, only teaching approaches were analysed in a review by Vogel and Harendza [15]. In a practical guide [14], a curriculum integration framework concerning the whole of simulation-based education was developed. Another review by Theodoulou et al. [16] was devoted to organizational aspects of training surgical skills only.

Information about training for measurement of blood glucose or taking nose, throat and skin swabs in simulation settings was not identified. However, skills such as venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation are basic for undergraduate medical education in different countries [5,13,15]. To the best of authors' knowledge, there is no paper in the literature that analyses the organization of simulation-based training of these skills in undergraduate medical education.

Aims and objectives

To respond to the focused organizational issue, the following aims were stated:

1. Critically appraise the organization (teachers, resources, pedagogy) of simulation-based learning of invasive procedures skills (venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation) according to the literature;

2. Create a theoretical framework for their organization in different contexts of undergraduate medical education.

The article reviews primary data about teaching different invasive skills in simulation settings [17-21]. The authors of the review also held consultations with specialists in simulation-based education. Dr Angus Cooper and Mr Ian Morrison from the Clinical Skills Center of Aberdeen University (UK) advised taking into account information about peer training and students' opinions in regard to the organization of simulation-based education. Furthermore, the Head of the Center for Simulation-based Learning and Accreditation of Specialists of Tver State Medical University (Russia), Dr Viktor Shekhovtsov, suggested considering points about the abilities of students to perform the skills after time, existing methodology of skills implementation, and cooperation process between skills centers and clinical departments.

Therefore, the following areas of focus were identified:

compulsion or optionality of simulation-based courses; trained year of undergraduate study; time between training in simulation settings and clinical practice; theoretical preparedness before skills training; teachers who trained students; existence of training by peers; size of student classes; time duration of skills training (number of hours for learning, frequency of skills repetition); training of skill alone or as a part of bundle; type of simulation equipment (low/intermediate/high fidelity); use of actors (simulated patients) during training; methodology of skills performance; type of skills performance assessment; type of feedback for students; skills performance improvement after training and after time; students' opinions about organization of simulation-based training; process of cooperation of skills centres with clinical departments.

Methods

Data collection

To achieve the stated aims and objectives, a critical literature review was performed.

PubMed and Cochrane databases were chosen to search for papers. The PubMed system contents diverse biomedical resources, including those devoted to simulation-based medical education. The Cochrane database is a base of randomized controlled trials.

The following keywords were used in combination with Boolean operators: simulat*, invasive, practical, basic, procedur*, skill*, undergraduate, curriculum, integrat*, continuing, education, injection*, urinar*, urethr*, intraven*, ven*, cathet*.

Titles and abstracts of identified articles were read and selected in accordance with the inclusion criteria.

These were:

1. Single language of publications, which should be the same as the review language (English) to allow readers to check the literature.
2. Target population of any paper should be undergraduate medical students or graduated medical students or qualified doctors if their experience during undergraduate study was analysed. Other healthcare specialties were not included due to differences of undergraduate education in comparison with medical doctors.
3. Any point of applying simulation technologies for specified invasive skills training should be considered in a whole publication or its part.

Exclusion criteria were not specified because they were opposite to inclusion criteria. Data from included articles were extracted in accordance with the objectives of the review.

The quality of each paper was analysed according to the assessment tools available for medical educational studies. They were the Medical Education Research Study Quality Instrument, the

Newcastle–Ottawa Scale-Education [22] and the ReBIP quality assessment tool [23]. The Joanna Briggs Institute tools were also applied [24].

Data analysis strategy

The data collected were analysed using a critical interpretive synthesis approach [25] because, firstly, a lack of primary information was identified in the scoping search, any available articles with different study designs were included and any valuable data were extracted for the review, paying attention to quality but not excluding any paper [26]. Secondly, the aims of the research are practice-oriented. There was an attempt to critically analyse and synthesise different points of the organizational problem of simulation-based training of invasive procedures skills.

Results

General characteristics of the literature pool

Combinations of the keywords used, along with numbers of results, are indicated in [Table 1]. After applying the inclusion criteria, 19 papers were chosen. However, one article [27] was excluded due to uncertainty of what skill was considered – central or peripheral venous catheter insertion. An e-mail to the authors for clarification did not elicit a reply. A flowchart of the inclusion process is presented in the supplementary materials [Figure 1S].

Because of study design diversity across the papers, it was impossible to apply quality assessment tools systematically. To find a common denominator, several checklists from one scientific team of the Joanna Briggs Institute were applied in accordance with study designs [24]. Some questions were adapted for the medical education field. Individual forms were filled in first and then all results were integrated [Table 1S]. For better visualisation, the answers were marked with colour. Green indicated 'high quality directed' and ticks were calculated as a percentage for each paper. 14 from 18 articles scored 50%. After the assessment process, no paper was excluded due to the aim of extracting any available and valuable data.

Summary information from included articles [11-15,28-40], such as study designs, countries of authors' teams, departments of each author and years of publishing, are presented [Figure 1].

As for the most often considered skill, it was establishing peripheral intravenous access, which was mentioned in 14 papers [11-14,28,29,31-36,38,40]. Less frequent was urinary catheterisation and intramuscular/subcutaneous injections, which were discussed in seven [12,13,28,30,33,38,39] and four articles respectively [13,15,37,38]. Only two publications paid attention to venipuncture [15,40].

Areas of focus

Few courses described in the articles were compulsory [12,13,33,40]. An optional one was mentioned only in one paper [28]. According to ten publications, they were experimental rather than routine [11,29-32,34-37,39]. A recommendation of having structured courses was stated in one article [15]. Information from other publications was not identified.

Most undergraduates being trained in invasive skills were students in their first three years [12,13,28-36,39,40]. One article indicated the 5th year [37] and four papers did not provide this information [11,14,15,38]. Primary information about time between training in simulation settings and clinical practice was insufficient. According to the existing data, practice at hospitals was performed the same studying year as simulation-based learning [12,36,37,40].

Summarising the theoretical preparedness before training in invasive skills in simulation settings, it seems possible to distinguish formal didactic training during studying at medical school [12,28,29,36]; lectures, instruction and demonstrations by teachers before training [12,29-35,39]; multimedia materials, including instructional video and slides [11,15,34,37]; and a handbook with procedure description [13].

In regard to the teachers who trained students, there are non-physicians (skills center and faculty staff) [11,29,32,33,35,37] and physicians (departments staff) [12,30,32,35,39], which constitute a group of university teachers. The separate category is students' peers (students, senior students or tutors and residents). Moreover, there is a tendency and positive experience to shift training tasks from university staff to students' peers [13,15,31,33,36,38].

Across most of the papers, the size of a class ranged from 2 to 19 students [11,13,15,29-33,35,37,39]. There is another tendency: the fewer the number of trainees the better for learning processes. At the same time, the duration of individual lessons could be up to two hours [37]. As for frequency of skill repetition, primary information is not enough to draw conclusions. According to one publication [29] it was necessary to repeat up to 37 times of repetition to learn a skill. Duration of the training sessions was from one week [34] up to ten months [30], depending on the investigations context.

As for skills training alone, or as a part of bundle, seven articles mentioned the first option [14,29,34-37,39] and seven papers described another one [11,13,14,30-33]. Other authors did not consider this point.

Providing learning processes with low fidelity equipment was used in the delivery of seven experimental studies [29,30-32,34-36]. High fidelity options were mentioned in only one paper [39]. There was an interesting suggestion of using progressive training on low-, intermediate- and high-fidelity equipment during one training period with adding other skills at a higher level. The authors state that such training is more patient-oriented and resource- and cost-efficient [11]. Three articles did not specify [15,28,37] and others did not consider it.

To help learning processes, actors (simulated patients) could be an option [15,30,34]. However, students' peers can successfully act as such [32,37]. Moreover, this approach can provide an additional stimulus for students' better practising skills [37].

As for the methodology of skills performance, the authors of only three papers addressed this [11,32,36]. However, there is a strong tendency to apply an objective skills performance assessment where possible [28,31,32,34,39]. It can be Objective Structured Examination or Assessment using checklists and the additional option of video recording [28,32,34,37,39]. The self-assessment of learners is not recommended [40].

In regard to feedback for students, the preferred mode is individual, immediate, verbal and learner-driven after observation by peers or instructors [15,30-32,35-37]. Again, video recording is a helpful option for feedback [30].

Almost all publications that considered the problem of skills performance improvement reported success [11,15,29-32,36-39]. Only one article provided information that suggested no difference between intervention and control groups [34]. However, very few papers considered individuals' ability to perform skills after time. Unfortunately, declining tendency of skills performance quality was reported [31,36,39].

To help improve the organization of simulation-based training, students' opinions were considered across different surveys [12,13,29,30,33,34,37]. The process of developing cooperation of skills centers with clinical departments and no information was found, excepting indication that a physician could act as a teacher [12,30,32,35,39].

Full details of information extracted from the review pool are presented in the supplementary materials [Table 2S].

These results allowed the creation of a theoretical organizational framework [Figure 2]. Its intended audience is curriculum/policy makers. Some elements of the framework are detailed in accordance with review objectives. However, many of the components are not specified because, firstly, primary information was lacking and, secondly, these parts of the framework are dependent on other blocks, which can be different for different medical schools. Some details are results of critical thinking, for instance, 'salary for teachers'. Nevertheless, elements are not independent and cooperation between them – complexity – is indicated.

Discussion

General characteristics of the literature pool

It is worth paying attention to what countries authors are from. Almost all papers included in the review were written by authors from Europe and North America. One exception is the publication from Thailand [37]. Possible explanations could be limited leadership of researchers from developing countries, their low level of English, unfair practices when there is a preference of papers from prominent scientists, etc. [41]. Therefore, publishing in different countries/languages should be encouraged, because it will help to improve comprehensivity.

Implications for management practice

There is a lack of primary information and included publication diversity in this review. Study context influences variables too, resulting in different outcomes [14]. There is, as such, difficulty in providing a single recommendation in regard to the organizational issue. The only option is providing possible ways for curriculum/policy makers to respond to the proposed theoretical framework [Figure 2] based on the review results. It should help achieve both wider application and thoughtful integration of simulation-based learning of invasive skills in undergraduate medical curriculum. Moreover, the framework is open to improvement by practitioners.

It is possible to make the following comments regarding the framework;

Firstly, a unified methodology to train a skill should be established at least at country level to respond to healthcare requirements equally across different medical schools. This will improve transparency and quality of skills performance assessment and feedback. Furthermore, such an approach could create competitiveness for improving teaching to find the most efficient and cost-effective learning, because the start (skills performance methodology) and the end (graduation requirements for skills performance) points will be known.

Secondly, as mentioned in the 'Results' section, there is a tendency towards, and positive experience of, 'tasks shifting' the training in educational processes, which means that allocation of duties and functions from senior staff to other people who are able to perform them [42]. For simulation-based learning, it is shifting of tasks from university teachers to student peers, which saves senior specialists for more difficult training [11]. This tendency is congruent with analogue processes in Global Health issues [42]. Besides, peers can act as simulated patients by using, for example, plastic arms [30].

Additionally, video recording plays an important role for objectivity of both skills performance assessment and feedback for learners.

Finally, students' opinions are a valuable resource for assessing the organizational quality of simulation-based education. Feedback from learners can be as valuable as feedback for learners [33].

Limitations and strengths

The limitations and strengths of this review are intertwined.

Firstly, the review process was performed by one reviewer. However, scientific supervision and professional recommendations of specialists helped inform this process.

Secondly, all available papers, regardless of their quality, were included in the review. A method of critical interpretive synthesis to support the inclusion was conducted by the reviewer.

Thirdly, only English-language papers were used in the review, to help readers check the references. However, other important information could be in non-English publications.

There is a tendency to report positive results of skills performance improvement in papers that considered this issue. It can lead to positive publication bias. Although, negative experience would be valuable for analysing organizational issue as well.

Finally, it is difficult to precisely locate the boundary between management of simulation-based education and aspects of teaching processes. Pedagogical approaches are closely intertwined with organizational aspects. However, there was an attempt to consider different sides of the issue and create a comprehensive framework, which could be completed in a specific context [Figure 2].

Further research

It seems necessary to include more primary data to open up the objectives of this review. For instance, investigating teaching approaches to train invasive skills in simulation settings. It seems worthwhile to consider organizational aspects of the framework help both understand the context of a particular study better and adapt delivery in other educational establishments. It could provide a useful base to intertwine with other techniques of organizational development [43,44].

Conclusion

There is a lack of primary data in regard to simulation-based training organization (teachers, resources, pedagogy) of invasive procedures skills (venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation) in undergraduate medical education. Publications included in the review are diverse. However, using a critical interpretive synthesis approach allowed extraction of valuable information to create a theoretical framework, which is a template to complete and improve in a specific context.

There are several points in the framework that should be paid attention to. Firstly, a unified methodology of skills performance is required, at least within country. Secondly, there is a tendency of ‘task shifting’ the training from university teachers to student peers who can play the role of simulated patients. Additionally, video recording can be helpful for educational processes. Finally, students' opinions are valuable tool for assessing the organization of simulation-based training.

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Disclaimer statements

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Ethics approval

None.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Conflicts of interest

There are no conflicts of interest.

Biographical notes

Timur Valiev graduated from Tver State Medical Academy (Russia) and received the degree of Medical Doctor in 2014. He recently completed a postgraduate program, MSc ‘Global Health and Management’, at Aberdeen University (UK) in 2018.

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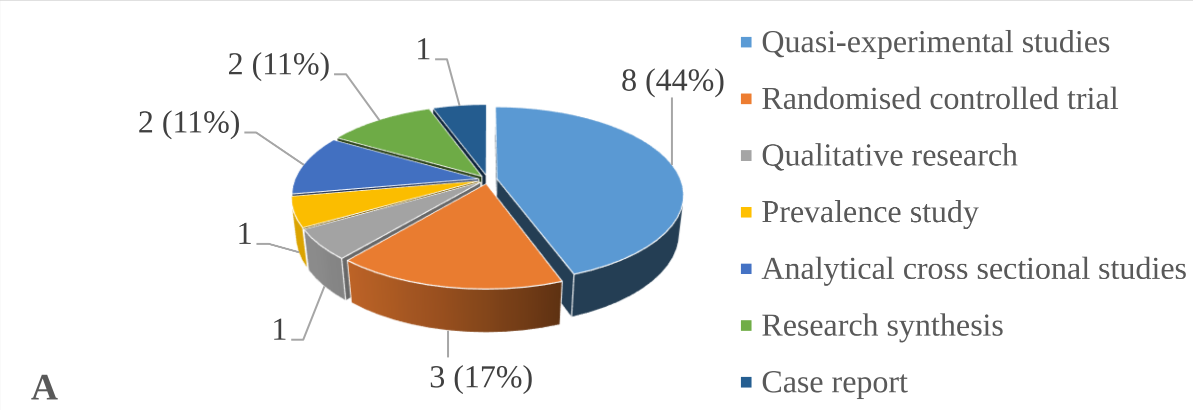
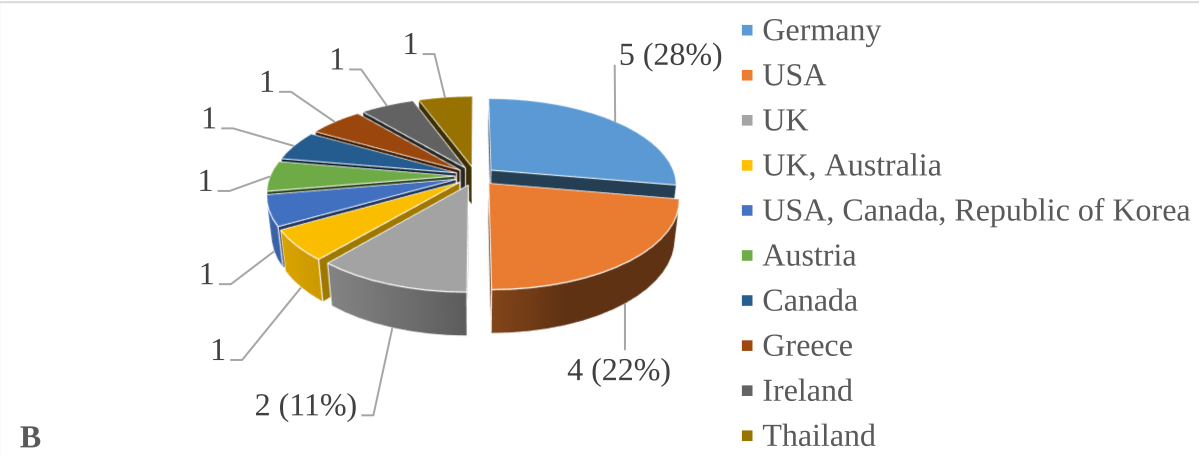
Table 1. Used combinations of keywords with Boolean operators for search and number of results for requests

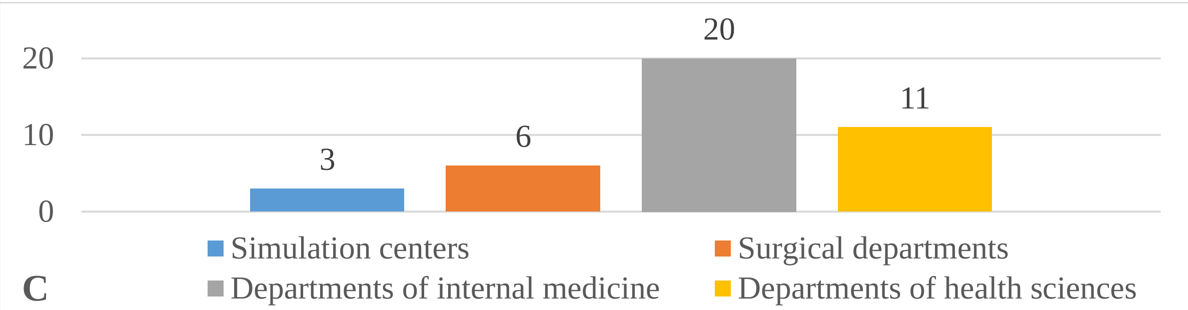
Search Requests	Results number for 'PubMed' (Basic Search)	Results number for 'Cochrane' (Mode "Title, Abstract, Keywords")
simulat* AND invasive AND undergraduate AND curriculum	40	3
integrat* AND simulation AND undergraduate AND education AND continuing AND curriculum	6	0
simulat* AND (invasive OR practical) AND (skill* OR procedur*) AND undergraduate	164	27
simulat* AND procedur* AND skill* AND undergraduate	188	56
simulat* AND (invasive OR practical OR procedur*) AND (skill* OR procedur*) AND undergraduate	404	101
simulat* AND basic AND skill* AND undergraduate	171	37
simulat* AND injection* AND undergraduate	7	2

simulat* AND urinar* AND undergraduate	8	1
simulat* AND urethr* AND undergraduate	1	0
simulat* AND intraven* AND undergraduate	20	8
simulat* AND ven* AND undergraduate	0	19
simulat* AND cathet* AND undergraduate	42	10

Figure 1. A – Number of papers with definite study design. B – Number of countries of authors' teams. C – Total number of each author departments. D – Number of publications by years







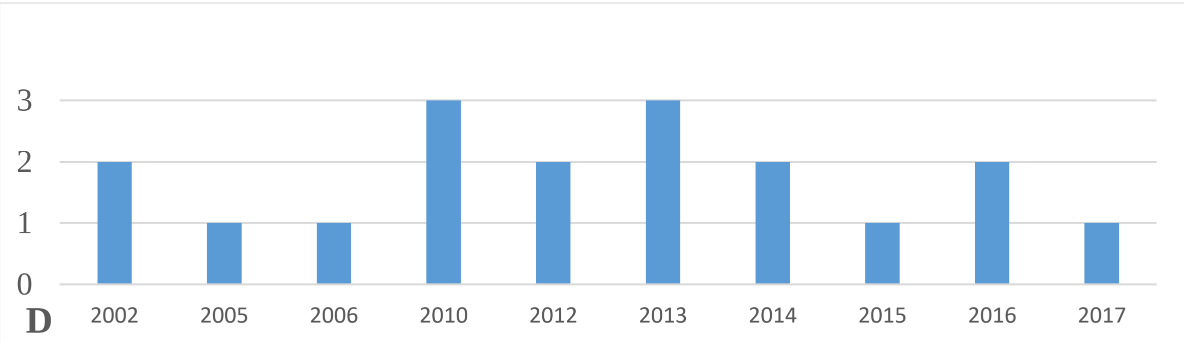
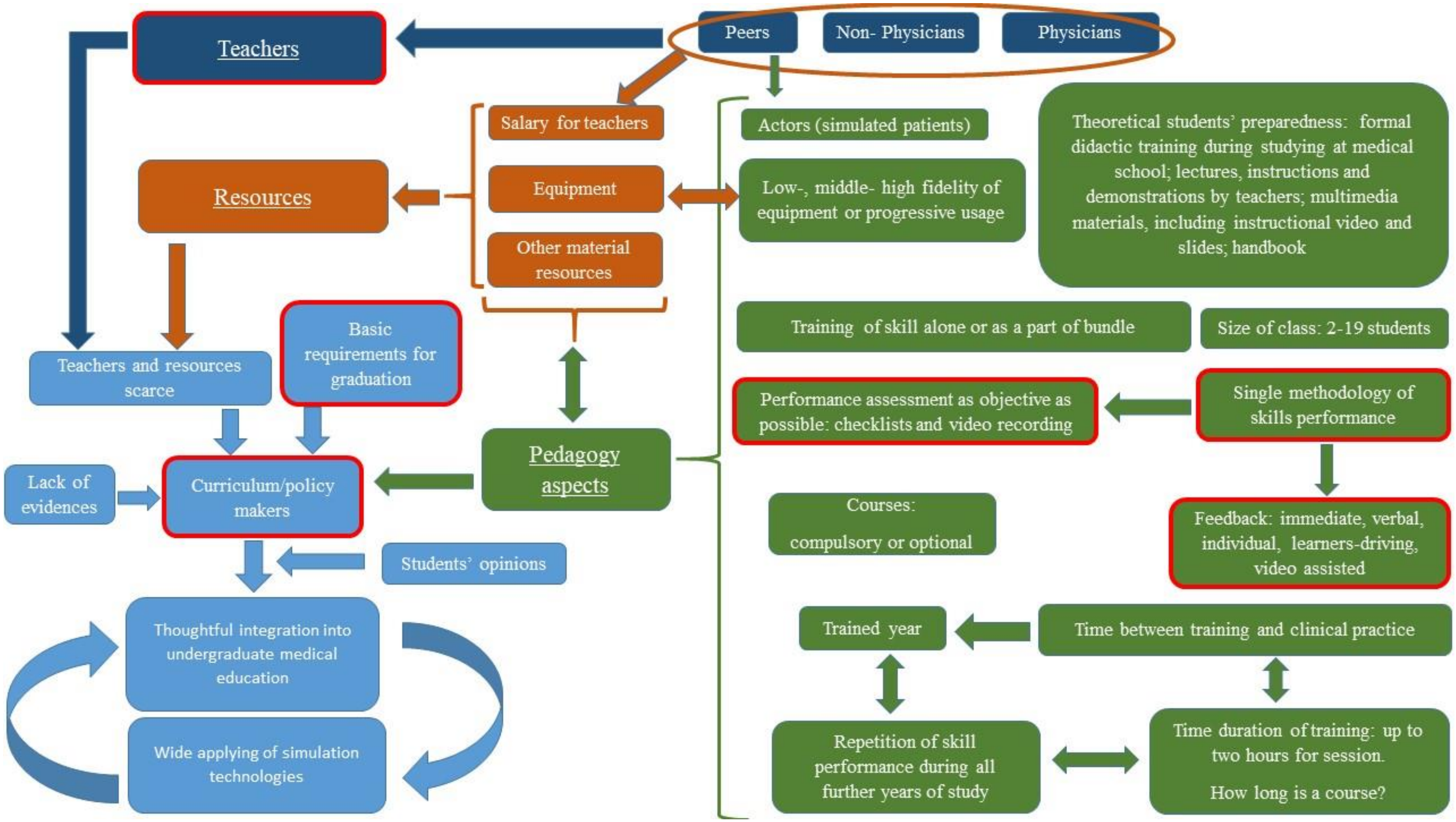


Figure 2. A theoretical framework for the organization (teachers, resources, pedagogy) of simulation-based training of invasive skills (venipuncture, establishing peripheral intravenous access, subcutaneous and intramuscular injections, male and female urinary catheterisation) in different contexts of undergraduate medical education.

The blocks with red borders are crucial parts of the construction. The elements concerning teachers are marked with dark blue colour. The elements of resources are marked with brown colour. Pedagogy aspects are presented on the green backgroun d. Cooperation between blocks are indicated with arrows.



Teachers
Peers
Non- Physicians
Physicians
Salary for teachers
Resources
Equipment
Other material resources
Actors (simulated patients)
Low-, middle- high fidelity of equipment or progressive usage
Theoretical students' preparedness: formal didactic training during studying at medical school; lectures, instructions and demonstrations by teachers; multimedia materials, including instructional video and slides; handbook
Teachers and resources scarce
Basic requirements for graduation
Training of skill alone or as a part of bundle
Size of class: 2-19 students
Performance assessment as objective as possible: checklists and video recording
Single methodology of skills performance
Lack of evidences
Curriculum/policy makers
Pedagogy aspects
Courses:
compulsory or optional
Feedback: immediate, verbal, individual, learners-driving, video assisted
Students' opinions
Thoughtful integration into undergraduate medical education
Trained year
Time between training and clinical practice
Wide applying of simulation technologies
Repetition of skill performance during all further years of study
Time duration of training: up to two hours for session.
How long is a course?

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